A RESEARCH INTO A NEW METHOD OF REFRIGERATION CHARGING AND THE EFFECTS OF IMPROPER CHARGING

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ABSTRACT

The purpose of this report is to provide the results of research evaluating a new method of air conditioning charging and the effects of improper charging. The method is the visual accumulator-charger device. The report identifies seven presently known charging techniques and compares them to the method tested, as well as its accuracy of charging.

A research on improper charging compared to the efficiency changes as a result of overcharge and undercharge conditions is the second part of the report.

The visual accumulator-charger device proved to be a practical field charging technique for air conditioning systems and demonstrated an accuracy over a temperature range of 70°F to 100°F.

It was also demonstrated that the improperly charged unit was dramatically affected.

PURPOSE

The purpose of this report is to provide the results of research evaluating a new method of air conditioning charging and the effects of improper charging. This new charging method is derived from a visual accumulator-charger device to be used in conjunction with a high efficiency condensing unit and a new or existing evaporator coil with capillary tube or fixed-orifice metering. Testing was conducted to determine the effect of the device on the ease of proper and accurate charging, maintainability of system efficiency, the protection from floodback, and the effect of overcharging and undercharging.

SCOPE AND LIMITATION

This report on the visual accumulator-charger device is limited to the effects of proper charging, ease of charging, protection from flooding, and maintainability of efficiency on a high efficiency condensing unit with a mismatched evaporator coil having a capillary metering device. This study does not address the effects of the device versus thermal expansion valve metering devices, nor does it compare the operating efficiencies of a capillary tube system as opposed to a thermal expansion valve system. These are planned for future studies. This report also does not address the effects of poorly maintained and dirty equipment on system operation. This will be addressed in a separate report.

INTRODUCTION

"Accurate, safe, and quick charging of split system air conditioning and refrigeration equipment utilizing capillary tube or other fixed-orifice metering devices at other than optimum conditions has long been a serious problem. With the advent of high efficiency cooling equipment this problem has become even more difficult. High efficiency equipment has also increased the problem of refrigerant floodback and slugging." The foregoing statements were made by Mr. Richard J. Avery, Jr., the inventor of a visual accumulator-charger device he calls the Accu-Charger.

A recurring theme in any number of publications, whether it be manufacturers' service bulletins, trade journal articles, or application engineering bulletins, is the fact that refrigerant overcharge, through the effect of floodback and slugging, is a major contributor to premature compressor failure. The following statements are from the Copeland Application Engineering Bulletin entitled "Liquid Refrigerant Control in Refrigeration and Air Conditioning Systems":

"One of the major causes of compressor failure is damage caused by liquid refrigerant entering the compressor crankcase in excessive quantities.

"Regardless of design there are limits to the amount of liquid a compressor can handle.

"The potential hazard increases with the size of the refrigerant charge and usually the cause of damage can be traced to one or more of the following:

1. Excessive refrigerant charge
2. Frosted evaporator
3. Dirty or plugged evaporator filters

4. Failure of evaporator fan or fan motor
5. Incorrect capillary tubes
6. Incorrect selection or adjustment of expansion valve
7. Refrigerant migration

"If an expansion valve should malfunction, or in the event of an evaporator fan failure or clogged air filters, liquid refrigerant may flood through the suction line to the compressor as liquid rather than vapor (1)."

Equal in importance to the adverse effects of refrigerant overcharge on compressor life is the effect of refrigerant overcharge or undercharge on the operating efficiency and economy of a split system air conditioner. An undercharge system will cause a loss in capacity with the addition of a disproportionate reduction in EER. An overcharged system will cause a slight increase in system capacity over the nominal, but at a higher cost in terms of electrical demand (kW). In addition, reduced equipment life expectancy is a direct result of refrigerant overcharge or undercharge.

PRESENT CHARGING TECHNIQUES

To fully understand and appreciate the concept of "proper" split system charging, a review of field-encountered variables is necessary. These variables can be broken down into at least four major categories:

1. The wide range of manufacturing design and performance
2. The broad range of ambient working conditions
3. Generally recognized charging techniques
4. Maintenance-oriented charging conditions

To appreciate the significance of the first category, consider the 48 manufacturers listed under the Certified Unitary Air-Conditioner Equipment Section in the current ARI Directory (2). Now multiply the names by the number of unit types listed for each manufacturer and again by the number of years the manufacturer has been in business. To be ready to service all these units just think about how many charging charts would be needed. This also gives an indication of how many different design philosophies and charging techniques that the serviceman has to understand.

Another variable to consider is the wide range of ambient outdoor and indoor temperatures experienced during the charging process. Depending upon location and the time of year, a normal summer temperature range of 70° to 105°F can be encountered. In addition, the wet bulb temperature, both indoors and outdoors, can have an effect on the charging accuracy.

Another variable, and probably the most debated, is that of "proper" charging techniques. A survey of the most recognized techniques would include:

1. Weighing -in the charge - Perhaps the most accurate method, provided that a manufacturer's chart or table is available. The technique is generally used on window units and refrigerator-freezers where the total refrigerant charge volume is relatively small. Once the system is evacuated, the exact amount of refrigerant can be added. On split system applications, except some heat pumps, the weighed-charge method is not commonly used since the amount of refrigerant already in the system is not always known, necessitating a total dumping of the existing charge to assure accuracy. Mild outdoor ambients would require a heated cylinder plus extra time and patience. In the interest of practicality and expense, this is not generally done.
2. Charging to full load or nameplate amps - This method is not acceptable to most equipment manufacturers. The full load or nameplate amp rating for a given size compressor is based on the maximum design operating pressures with a built-in safety factor to allow for maximum allowable current per Article 430 of the National Electrical Code(3). To charge a system at outdoor ambients less than the most extreme conditions (approximately 105°F or higher) would easily result in a gross overcharge.
3. "Feel the lines" or suction line sweatback - A recognized method that can be used with a moderate degree of accuracy under very carefully controlled ambient conditions such as those experienced when charging room air conditioners or refrigerator-freezers. It still requires both patience and experience. When this technique is applied to split central air conditioning systems, the accuracy dwindles. First, the effect of outdoor wet bulb temperature variations must be taken into consideration. Second, with the increased usage of high efficiency systems, the ratio of suction pressure to head pressure has now changed and varies from one manufacturer to another.
4. High and low side gauges - This method is very useful as a diagnostic service tool and is commonly used for charging purposes as well. It is very dependent upon the experience level of the serviceman and his ability to interpret correctly under a wide variety of circumstances. Conditions such as outdoor ambient, the efficiency rating of the system (determines suction to head pressure ratio), and the experience level of the individual can affect the accuracy of the charging procedure. In addition, the time element must be considered when using low side vapor charging since mild ambients cause lower pressure in refrigerant cylinders.
5. Manufacturers' charts and tables with high and low side gauges - A very accurate method if the source of information is available and kept up to date. The degree of accuracy can vary depending upon the recommended charging technique of a specific manufacturer. Variance in unit size can also affect accuracy. The experience level again comes into play, both from the standpoint of interpreting gauge readings, as well as the time factor required to obtain a representative sample of manufacturer's data.
6. Superheat charging - This has long been recognized as being one of the most accurate field charging techniques. It requires a thorough knowledge of the refrigeration cycle and, in practice, a great deal of patience since system stability is critical for optimum accuracy. The serviceman's experience level is again important since compensation for suction line pressure drop, outdoor ambient temperature, and indoor entering air conditions must be taken into consideration.

NOTE: A brief description of the term superheat is necessary to understand how it applies to air conditioning, both in terms of proper system design as well as proper charging. Superheat is defined as the amount of heat energy (sensible) that a vapor can absorb beyond its saturation or change-of-state temperature. In the design of capillary tube or fixed-orifice evaporators, a compromise value of 10-15°F superheat at ARI design rating conditions (95°F outdoor DB, 80°F DB/67°F WB indoor) is generally acceptable depending upon the manufacturer's design specifications. Less than this could result in a refrigerant floodback situation. More than this can cause premature compressor motor winding failure due to heat because the return suction gas is the primary means of cooling most compressor motor windings.

The actual process of measuring and adjusting superheat in a split system air conditioner involves:

A. Attaching a thermometer (electronic types are the best) to the suction line as close as possible to the compressor.
B. Attach the low side or compound gauge to the suction service port.
C. After allowing the system to stabilize approximately 12-15 minutes, read the suction line temperature. Next subtract the saturated suction temperature (temperature corresponding to actual suction pressure) from the suction line temperature. The resultant difference is superheat.
D. Correct the superheat temperature for line loss and outdoor ambient.

Proper system superheat is critical from both the charging and the operating standpoint.

7. The Doppler Charging Technique - A relatively new method for charging with ultrasonic sensors utilizing the Doppler effect. The ability to "sense" the refrigerant in the system contributes greatly to the accuracy of the charge. It should be noted that the experience level of the serviceman is important since accuracy requires the correct interpretation of the audio signals.
8. Visual Accumulator-Charger device - A recent development that allows a serviceman, regardless of his level of experience, to charge a system to minimum safe superheat. Incorporated in the design of the device (See Figure 1) are a metering orifice and an aspirator which allows liquid refrigerant charging on the low side. This allows time saving. In addition, a built-in sight glass, in conjunction with a thermometer well, permits accurate charging over a wide range of ambient conditions both indoors and outdoors. Neither the size of the unit nor the variation in charging specifications from one manufacturer to another has any effect on the ability of the device to ensure an optimum and proper charge every time.

Last in the listing of field-encountered variables is the heading "maintenance-oriented charging conditions." Included in this category is improper air flow due to such factors as dirty condenser, dirty evaporator, duct or plenum air leaks, evaporator size, and open or closed diffusers and grilles. Each component will have its effect on the overall system performance, and should be compensated for and/or corrected during the charging process.

THE EFFECT OF IMPROPER CHARGING

Improper charging can best be defined as either a refrigerant overcharge or undercharge when compared with the manufacturer's charging specifications, at standard ARI rating conditions. Either condition will have a detrimental effect on the system, both in terms of equipment life expectancy as well as operating efficiency and economy.

An undercharged condition will create abnormally high superheat which has an adverse effect on compressor motor winding cooling. The long term effect will be the eventual breakdown of motor winding insulation with premature compressor failure as a result. In extreme cases, due to the repeated opening of the internal motor overload protector, a much faster failure could occur.

From the operational standpoint, it is calculated that a refrigerant undercharge will cause the system capacity to decrease corresponding to the amount of undercharge. This is caused by a loss of refrigerating effect due to increased superheating of the refrigerant vapor. As the superheating increases the weight of the vapor decreases, resulting in a loss of refrigerating capacity, since the compressor is now pumping a less dense vapor. It is expected that the electrical demand of the compressor will decrease but at an unknown rate of change.

A refrigerant overcharge can reduce the life expectancy of a compressor due to the effects of liquid floodback, slugging, and motor overheating caused by abnormal heat pressure and/or compression ratios. Floodback is the continuous return of "liquid refrigerant" in the suction line to the compressor. A consequence of flooding is oil dilution which results in the poor lubrication and overheating of bearing surfaces. Slugging can be defined as an occasional return of liquid refrigerant to the compressor resulting in hydraulic compression which, if extreme, will result in broken components. Flooding and slugging can also cause motor overheating from a locked motor condition. This results in the repeated tripping of the overload protector which eventually leads to a motor burnout.

The effect of overcharge on system operating performance is the opposite of undercharge. An increased volume of refrigerant will cause the evaporator superheat to decrease until the maximum refrigerating effect is reached. Since the weight of the refrigerant vapor has now increased, the compressor will be forced to pump against a higher head pressure. As liquid backs up in the system, effective condensing surface area decreases with a corresponding rise in head pressure. An increase in motor current draw can be anticipated as a result.

TEST SET UP AND PROCEDURES

To experimentally determine the effects of the visual accumulator-charger device, a split high efficiency (9.0 SEER) air conditioning system, consisting of a 1½ ton condensing unit and a 2 ton blower-evaporator, was installed with 37 feet of interconnecting refrigerant lines. A valving manifold was installed to allow the system to be tested with or without the device. (See Figure 2.) The blower-evaporator was located in an "indoor" room with 80°F DB/67°F WB entering air conditions, while the condensing unit was located in an "outdoor" room where the ambient could be maintained at 70°F, 82°F, 95°F, or 100°F.

Temperature monitoring and recording were done by means of copper-constantin thermocouples interfaced with a Hewlett Packard computer. The computer was programmed to calculate, based on the input data, the following: enthalpy difference, total Btuh, sensible Btuh, percent sensible, and EER. In addition, the system kW was monitored and recorded. A constant evaporator blower airflow of 725 cfm was used, having been calculated by the heat rise method. Thermocouple error, based on calibration, was ± 0.5°F on both dry bulb and wet bulb measurements.

The actual test procedure began by first establishing a standard reference point at ARI design rating conditions (95°F DB outside, 80°F DB/67°F WB inside). Performance data was collected after having charged the system to the manufacturer's "factory spec." by test method #5. The system was then recharged utilizing the device and data recorded. Subsequent tests were then conducted at outside ambient temperatures of 70°F, 82°F, and 100°F to determine the effects of the device on system capacity and efficiency when compared to "standard" methods of charging at the same respective ambients.

To determine the effects of a refrigerant overcharge (23% by weight) on system capacity and efficiency, comparative tests were run, with and without the device, at the 82°F and 95°F outdoor ambients.

A third series of tests were conducted at the 82°F and 95°F outdoor ambients to determine the effects of a refrigerant undercharge (23% by weight) on system capacity and efficiency. Once again, data was collected with and without the device in the system.

Sampling error was maintained at the minimum test condition tolerances as allowed by the ANSI/ASHRAE 37-78 Standards(4).

EVALUATION

The curves on Figure 3, entitled "Charging Ability of Visual Accumulator-Charger Device Versus Charging to Manufacturer's Specs", represents the charging ability of the visual accumulator-charger device over a range of outside ambient temperatures when compared to the charging ability based on "manufacturer's specifications" (test method #5) at the same respective ambients.

The manufacturer's laboratory-derived charging specs were used as a reference point to establish a norm representing charging ability, or accuracy.

Starting at the 100°F temperature condition and working down to the 70°F temperature condition, the percentage differences in data points, comparing both curves, were 0%, 1.2%, 0%, 2.1%, and 7.1% respectively. It should be noted that the comparative data points fall well within the range of the sampling error boundaries with the exception of the points at the 70°F outdoor ambient.

At the 70°F temperature condition a deviation from test procedure occurred, in that the reference charge was based on the accumulator-charger device. Instead of recharging the system based on manufacturer's specifications, as had been done at the other temperatures, the valve manifold was changed to remove the accumulator-charger device from the circuit. The result was an increase in efficiency (EER) since the capacity increased while the demand (kW) remained unchanged. An analysis of the data indicates that the accumulator feature of the device caused a small amount of refrigerant to be stored in the system which, upon removal of the reservoir, put the system in an overcharged condition. The actual data is presented in tabular form:

Device Mode	Head Pressure Lb.	Suction Pressure Lb.	Sat. Suct. Temp. °F	Suction Temp. °F	Superheat Temp. °F
With	172	63.5	36.5	70	33.5
Without	183	70.0	41.0	79	28.0

The data confirmed the results of what is to be expected from an overcharged condition. This was indicated by an increase in head pressure and suction pressure with a corresponding decrease in superheat. A duplication of the standard test procedure at the 70°F condition would be expected to produce data within the range of the sampling error.

Figure 4, entitled "Effect of Refrigerant Overcharge or Undercharge on System Performance Compared with Proper Charge," compares the effects, on system capacity and demand (kW), of a 23% refrigerant overcharge or undercharge against a proper charge.

The proper charge set of curves have been derived from the averaging of the data points as presented in Figure 3.

As illustrated by the curves, the undercharge condition affects the system operating efficiency and operating cost by causing a rapid decline in total capacity as the outdoor ambient increases, while at the same time the electrical demand (kW) is increasing at a slower rate. The resultant drop-off in system efficiency (EER) is very pronounced. The 23% by weight undercharge changes the EER from 8.31 to 5.49 at 95°. This is a 52% increase in operating cost. As a result, for this 1½ ton unit, the annual operating cost can be expected to be increased by (1.23 kW x 1700 Hrs x $.07) = $133.63. In addition, the long term effect of elevated suction gas temperatures caused by this undercharged condition will reduce the life expectancy of the compressor. Some manufacturers claim this to be as much as 50%.

The results of overcharge on system performance, as shown by the curves, is a slight increase in capacity over the proper charge but at a higher cost in terms of electrical demand (kW). As the outdoor ambient increases, the capacity and demand both approach an intersecting point with the proper charge curve.

The 23% by weight overcharge changes the EER from 8.31 to 8.35 at 95°. This is a 0.5% decrease in operating cost. For this 1½ ton unit the annual operating cost can be expected to be reduced by (.012 kW x 1700 Hrs x $.07) = $1.43. NOTE: The estimated dollar values can vary with different weather zones and utilities.

The greater consequence of an overcharged system, as noted in Figure 4, is the effect of flooding. As the outdoor ambient increases, the refrigerant floodback becomes more pronounced. The floodback has a two-fold negative effect: first, it causes an increase in electrical current draw since the compressor is now pumping against a higher pressure differential; second, it dramatically reduces the life expectancy of the compressor since it was not designed to pump liquid refrigerant.

Although it is not graphically displayed, the technical ability required to accurately charge a system by means of the visual accumulator-charger device was determined by subjecting a number of individuals, with different levels of professional air conditioning service experience, to the charging procedure. It was found that, regardless of experience level, the individuals were able to correctly charge the system each time. This is not to imply that any individual off the street can become an immediate expert in system charging. A basic understanding of refrigeration theory is essential from both the service and installation standpoint.

It should also be noted that the findings of this report verify those obtained, on a preliminary basis, in a report issued by an independent testing facility. The preliminary testing was conducted on a very limited basis.

CONCLUSION

The visual accumulator-charger device proved to be the most practical accurate field charging technique for split system air conditioners utilizing capillary tube or fixed-orifice metering. This superheat charging method was demonstrated to be consistently accurate over a temperature range of 70°F - 100°F.

The charging procedure allowed for an easily learned safe charging technique that will consistently result in proper system charge regardless of the range of field charging conditions or expertise.

The device also prevented floodback to the compressor and, as a result, will allow the installation of a high efficiency condensing unit with an older mismatched evaporator coil or a new evaporator coil without the risk of premature compressor failure.

Compared to any recognized charging technique, the ability of the visual accumulator-charger device did not detract from the operating efficiency of the system.

It was also demonstrated that the operating efficiency of the unit was dramatically affected by varying the refrigerant charge from a 23% overcharge to a 23% undercharge. An overcharge lowered the operating cost by 0.5% but increased the floodback problem. The undercharge increased the operating cost by 52% with a loss in cooling capacity which can cause extreme comfort problems.

By virtue of its ability to assure a proper system charge, the device benefits the end user in a number of ways. First, by preventing an overcharged condition, it extends the life expectancy of the system while at the same time limiting excessive demand. Second, by preventing an undercharged condition, it allows for maximum capacity utilization while again extending the life expectancy of the system.

REFERENCES

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2. ARI Directory of Certified Unitary Air Conditioners, Air-Conditioning and Refrigeration Institute, Arlington, VA.

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4. ANSI/ASHRAE Standard 37-78, "Methods of Testing for Rated Unitary Air-Conditioning and Heat Pump Equipment," American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

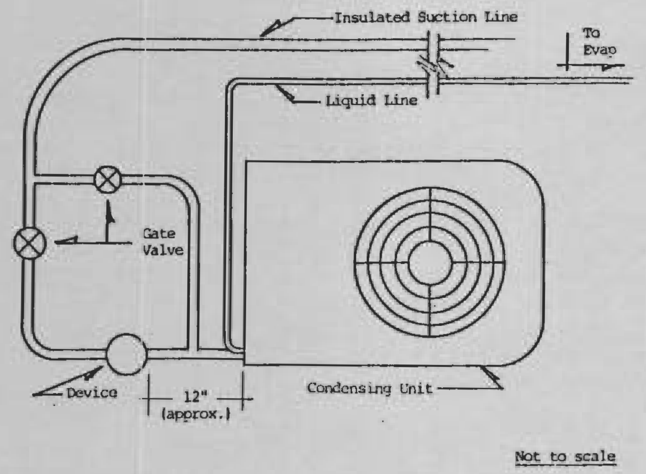
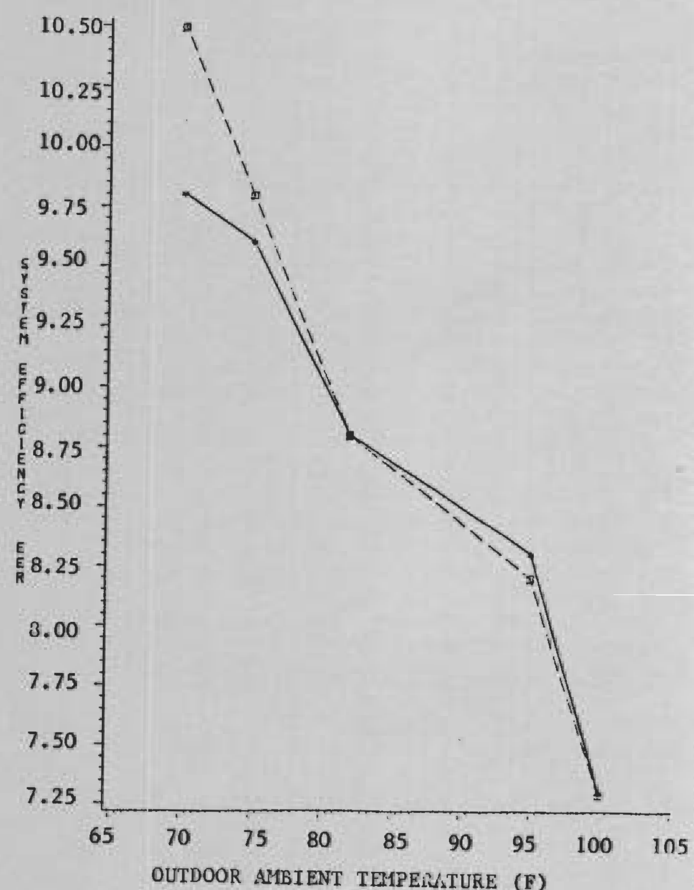


Figure 2 Valving Manifold Test Set Up



LEGEND DEVICE WITH WITHOUT

Figure 3 Charging Ability of Visual Accumulator-Charger Device Versus Charging to Manufacturer's Specification

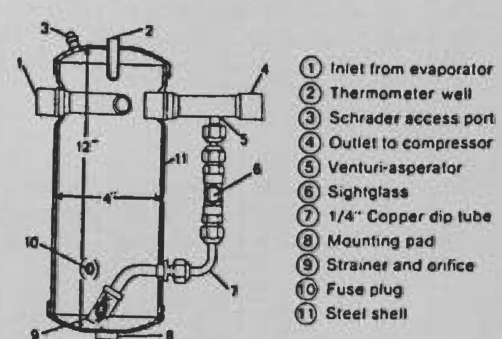


Figure 1 Accumulator-Charger Device

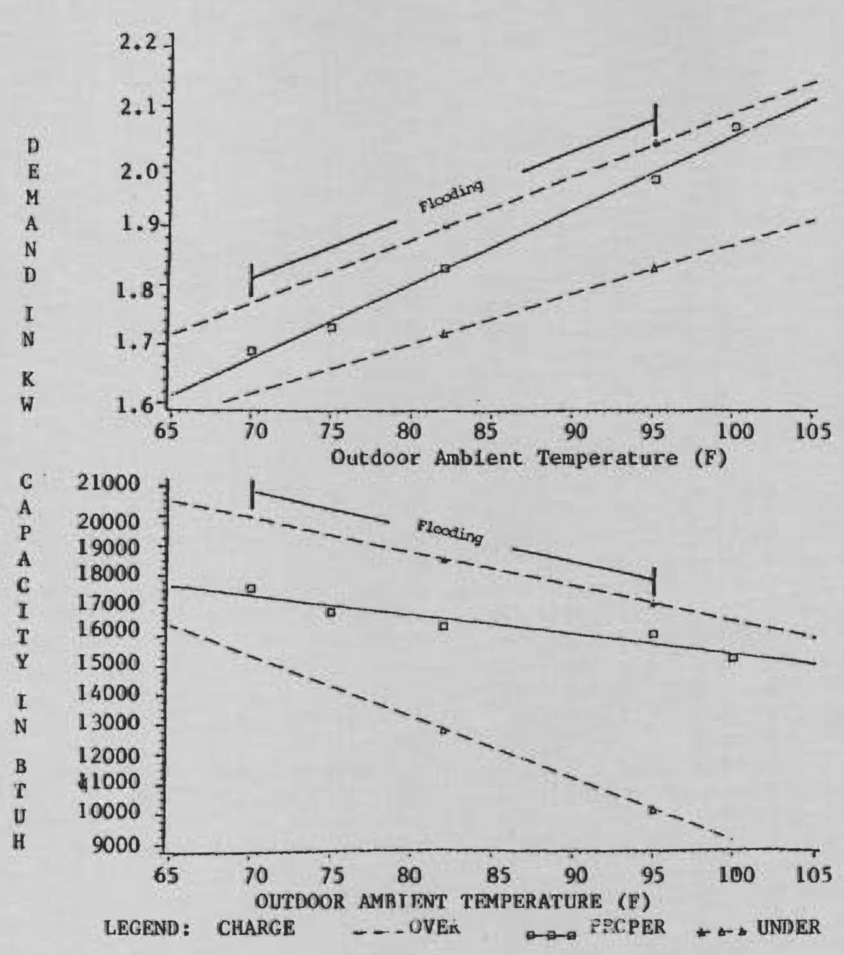


Figure 4 Effect of Refrigerant Overcharge or Undercharge on System Performance Compared with Proper Charge